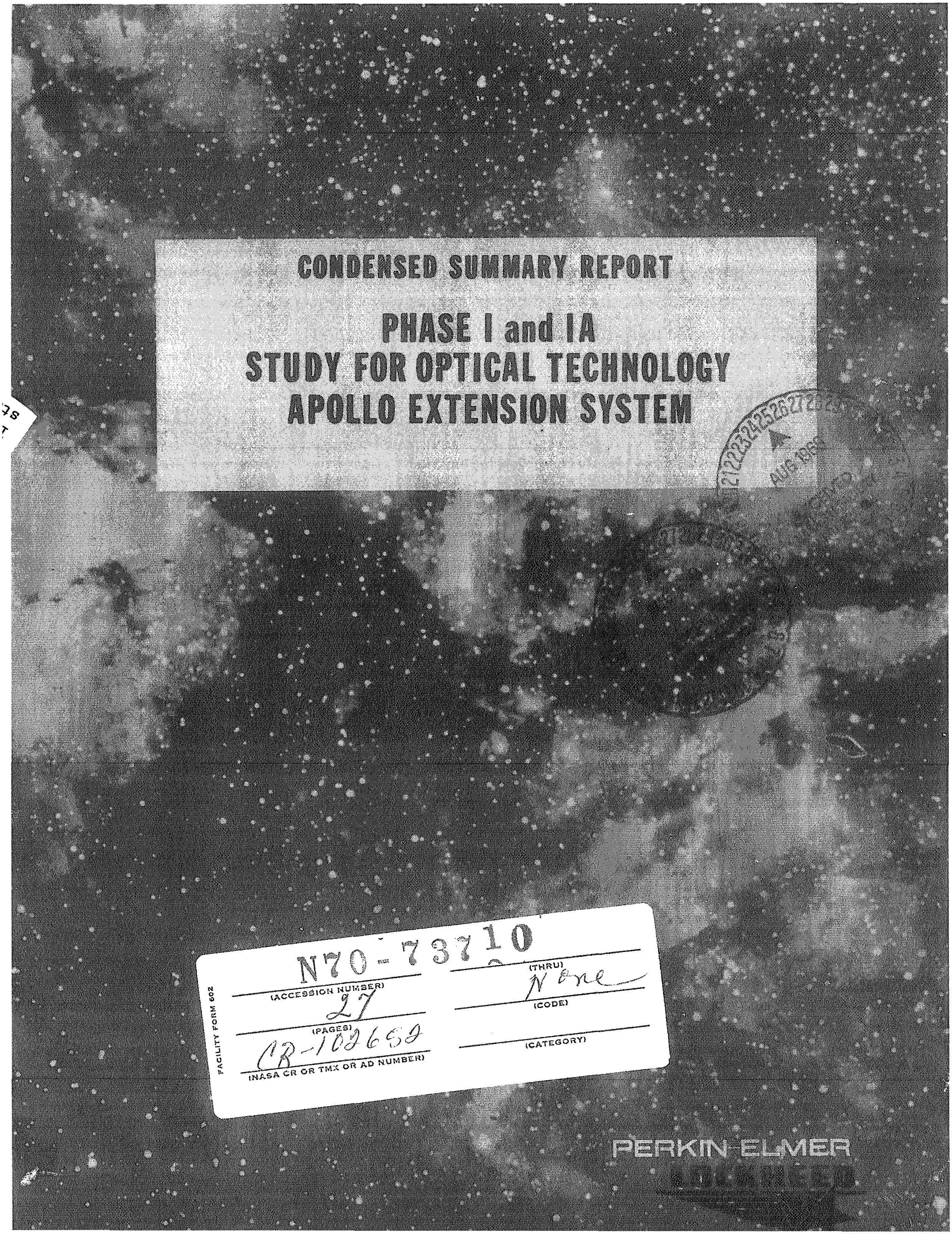

CONDENSED SUMMARY REPORT

PHASE I and IA
STUDY FOR OPTICAL TECHNOLOGY
APOLLO EXTENSION SYSTEM

PERKIN-ELMER

PERKIN-ELMER

ELECTRO-OPTICAL DIVISION NORWALK, CONNECTICUT

LOCKHEED

NO CF.

ENGINEERING REPORT NO. 8500A

PHASE I AND IA
STUDY FOR OPTICAL TECHNOLOGY
APOLLO EXTENSION SYSTEM
(Condensed Summary Report)

DATE: 8 NOVEMBER 1966

PREPARED FOR: ASTRIONICS LABORATORY
MARSHALL SPACE FLIGHT CENTER
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
HUNTSVILLE, ~~ALABAMA~~

CONTRACT: NAS8-20255

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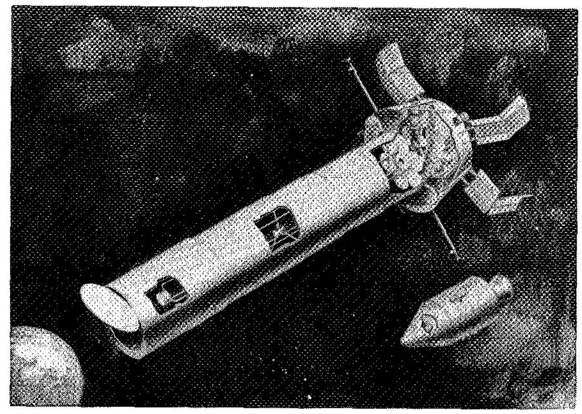
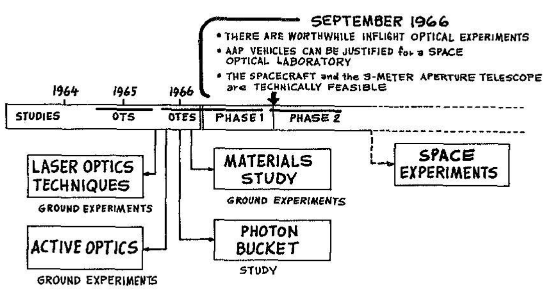
STUDY OBJECTIVE

The objective of the Optical Technology Apollo Extension System study (OTES) is the crystallization of a program for the orderly and timely development of space optical technology. The OTES Program is dedicated to the concept that the development of future optical payloads will be advanced through the conduct of scientific and engineering experiments onboard an Earth-orbiting vehicle. Phase I of the OTES Program dealt with the needs for space optical technology and how that technology could be developed. Numerous optical flight experiments were investigated and justification for conducting these experiments in space were studied and documented.



RELATIONSHIP TO OTHER NASA EFFORTS

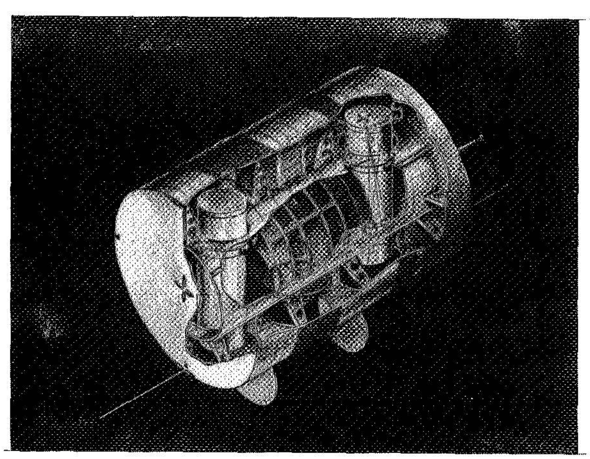
PROGRAM HISTORY



The interrelationship between the key study projects and the laboratory investigations for the OTES Project is shown. The system studies, such as the OTS (Determination of Optical Technology Experiments for a Satellite) and the present OTES Project, focus the attention of the NASA management on critical technical areas of the present state of the art and on pertinent Earth laboratory work. The ground experiments provide solutions to some key engineering questions and must be completed in advance of the space experiments.

DETERMINATION OF OPTICAL TECHNOLOGY EXPERIMENTS FOR A SATELLITE

The OTS Study (NAS8-11408, 1964-1965) was a study conducted for MSFC with a primary emphasis on laser communication experiments that could be conducted from a Saturn IB/Centaur <u>unmanned</u> spacecraft. Two laser telescopes, each with a 32-inch aperture, were to be mounted in a cylindrical vehicle weighing 6000 pounds. A total of 13 space experiments were recommended;

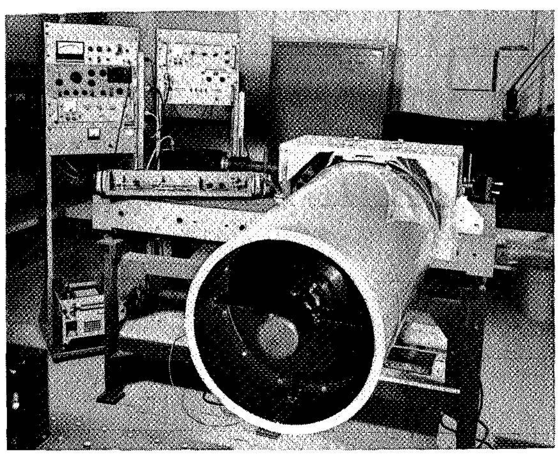


ten experiments were of an engineering nature and three experiments were science oriented. All ten engineering experiments and two of the three science experiments continue to be recommended experiments for the OTES Program. The basic differences between the OTES Program and the OTS Study were in the breadth in scope of the space experiments: OTS concentrated on laser communication experiments while OTES included large space optics as well. The OTES experiment list has been increased to 30 experiments recommended by Perkin-Elmer.

The launch vehicle for the OTES Program is the Apollo Saturn booster of the AAP. Thus, the program can take advantage of astronauts to assist in the conduct of experiments. OTES experiments were investigated based on optical applications in astronomy, planetology, meteorology, navigation, and atmospheric sciences. The effort was expanded by including Lockheed as the principal subcontractor to investigate the details of the entire system.

LASER/OPTICS TECHNIQUES

Project for MSFC (NAS8-20115) is a laboratory oriented laser and optical techniques project designed to develop the hardware approaches applicable to future deep-space optical communication systems.

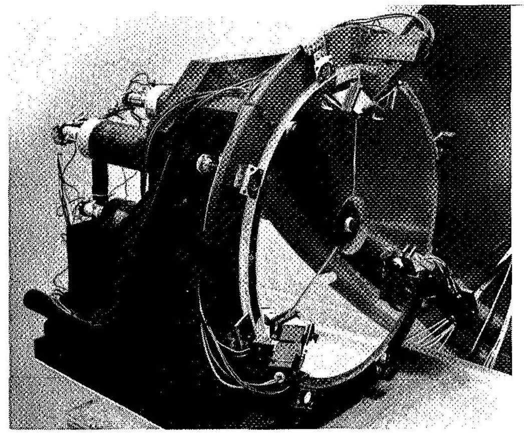


Analyses and laboratory demonstrations have been conducted in the following areas:

- Isolation of the transmitter channel from the receiver channel by 115db including hardware development and demonstration in the laboratory.
- Analysis of rotation-about-the-line-of-sight (RLOS) systems.
- 1/10 arc-second laser beam tracking hardware and demonstrations in the laboratory.
- 50 arc-second point ahead hardware and demonstrations in the laboratory.
- Measurements of the fluctuations of the far-field laser beam.
- Coarse guidance technique analysis and optical development suitable for a space vehicle laser communicator.
- Analysis of laser telescope packaging requirements.
- Engineering evaluation, design, construction, and testing of a half scale functional engineering model of a laser communication experiment package which included laser/telescope, tracking subsystem, acquisition subsystem and point-ahead subsystem.

The interrelation between this project and the OTES Program is that the OTES establishes the system concepts, systems analysis and laser/optical hardware needs for deep space laser communications while the Laser/Optics Techniques project converts these ideas into functional hardware-demonstratable in the laboratory.

ACTIVE OPTICAL SYSTEMS FOR SPACE STATIONS



Project for LRC (NAS1-5198) is a laboratory-oriented project directed toward solving the problems of large diffraction-limited orbiting astronomical telescopes. The project approach is to sense the figure of the primary mirror in real-time, analyze the data and then, through the use of precise servomechanisms, alter the figure of the primary to its optimum value. This figure control operation is designed to keep the primary diffraction limited. The deviation from a perfect surface is to be 1/50 wave in space even in the presence of disturbing thermal gradients from the spacecraft observatory. The Active Optics concept at Perkin-Elmer is:

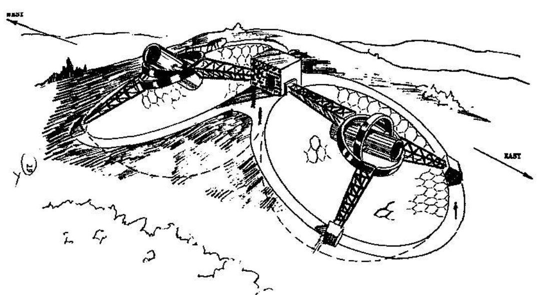
- precise figure measurement in real-time with a space-worthy technique.
- precise figure change to maximize performance of the primary using one of three "active" techniques:
  - segmented primary mirror
  - thin mechanically deformable primary mirror.
  - thermally deformable primary mirror.

The Active Optics Project team at Perkin-Elmer conducted the analyses and associated laboratory work necessary to demonstrate the segmented approach to NASA on September 30, 1966. During this demonstration, three segments of a 20-inch diameter mirror were aligned to each other, with a precision equivalent to the original uncut mirror (1/30 wave average), by the phase measurement interferometer and the mirror actuators.

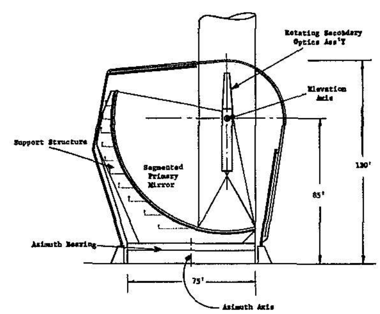
The relationship between the Active Optics Project and the OTES is quite similar to that described above for the Laser/Optics Techniques Project. The OTES addresses itself to the needs of future large orbiting optical systems and, in turn, develops the active optics specifications. Simultaneously in the laboratory, the Active Optics team does the optical and electronic work necessary to develop the equipment which will meet the specifications .

GIANT-APERTURE TELESCOPE STUDY FOR JPL

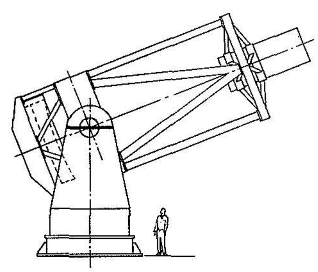
The objective of this study is to reduce to practice the use of giant-aperture telescopes as ground receivers for spacecraft communications. The study has extended the initial theoretical work done during the OTES Study (coherent laser communications using the CO_2 laser) which is a necessary step before the ultimate decision is made on design details of the ground telescope receiver. There is a considerable amount of difference between the design of a 10-meter incoherent telescope receiver (photon bucket) at 6328Å and a 4-meter coherent telescope receiver at 10.6 microns. For the space optics experiments considered in the OTES Program, the lasers which were evaluated during Phase I included helium-neon at 6328Å, argon at 4880Å, ruby at 6940Å, yttrium aluminum garnet at 1.06 micron, and carbon dioxide at 10.6 microns. The JPL work was extended in turn (for example, the incoherent laser communication system calculations were performed for 10.6 microns in the OTES). Also, the JPL study was principally concerned with factors which affect the ground telescope receiver. Thus, it was logical to derive the upgoing beam spread of the 4880Å beacon in the OTES study rather than the JPL study.



Fixed Disk Incoherent Photon Bucket at 6238Å



Rotating Disk Incoherent Photon Bucket at 6328Å



Coherent Ground Telescope at 10.6 Micron

APPROACH AND ASSUMPTIONS

The Perkin-Elmer/LMSC approach to the Phase I of the OTES (the Experiments Study Phase) was to study the prospective applications of optical technology in space. By understanding the needs for the future, those experiments that must be conducted today become clearer. The role of the Optical Technology Experiment System is to provide for the timely development of optical technology in support of future space applications through the performance of scientific and engineering experiments from a satellite test bed. Thus, the Perkin-Elmer/LMSC team identified experiments for an OTES based on future needs in:

- astronomy/astrophysics
- deep-space telemetry
- atmospheric science

As the experiment details developed through the use of analytical tools (such as performance calculations, modeling, and parametric studies) the experiments were subjected to three tests:

Test 1. Does the candidate experiment provide a key answer to engineering questions?

Test 2. Must the candidate experiment be conducted in space?

Test 3. Does the candidate experiment lead to important scientific activity?

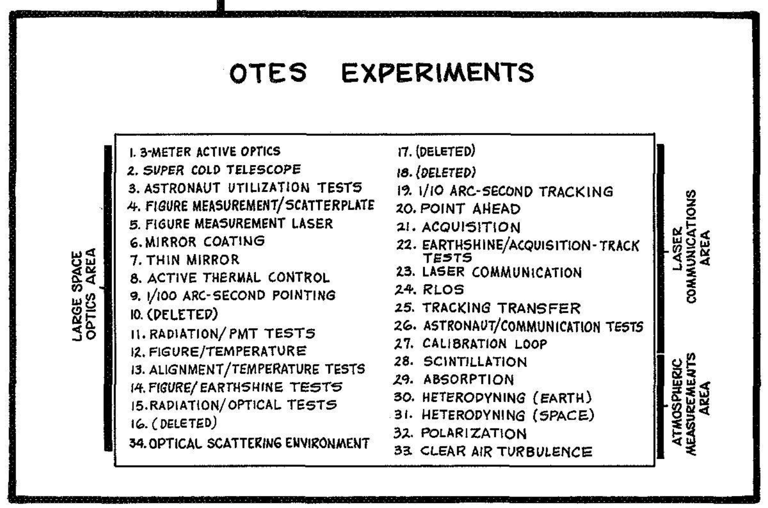
If at least two of the three answers to the above questions were in the affirmative, further details were developed on the proposed experiment. In addition, throughout the investigation, experiments which would be worthy of being conducted on spacecraft in the Apollo series were sought. It became apparent during the course of the study that some experiments in optical technology, which can best be conducted in space, should be conducted prior to an OTES flight. Certain experiments could be conducted on smaller vehicles than the contemplated Saturn V AAP System or could be launched "piggy-back" on earlier Saturn V flights as part of the ATM Program. Experiments in this category were identified to MSFC and OART; however, until another space optical project becomes approved, they will be carried along by the OTES as recommended experiments.

The question of highest importance to a space optical technology program such as the OTES or the OTS, is that of aperture diameter for the laser telescope. Because the OTS was basically optical communication oriented, the aperture selected for conducting the space laser communication experiments was approximately 1 meter. (It was later proved in the OTES Phase I Study that 0.8 meter aperture was the optimum choice in a weight tradeoff using 6328A as the deep-space transmitter. The optimum aperture using 10.6 microns as the deep-space laser transmitter is 1.5 meters.) However, the OTES is broader in scope than the OTS and the important area of astronomy must be considered. For that reason, various apertures (1/2 meter, 1 meter, 2 meters, and 3 meters) were considered during the course of the program. Apertures larger than 3 meters were not considered because they would not fit into the Saturn V shroud. Apertures smaller than 1/2 meter were eliminated because they do not represent reasonable utilization of the Saturn launch vehicle.

LMSC was instructed to investigate spacecraft configurations adaptable to each of these apertures for the telescope. The advantages and disadvantages of each spacecraft configuration considered for each of the telescopes can be found on Page 4 of the LMSC discussion (following this section). From an optical technology point of view, the larger the aperture (over 1 meter), the more valuable the experiments. From the astronomerspoint of view, the larger the aperture (2 to 3 meters), the more interest generated throughout the astronomical community. However, the difficulty and length of the program increases relative to the increase in aperture diameter.

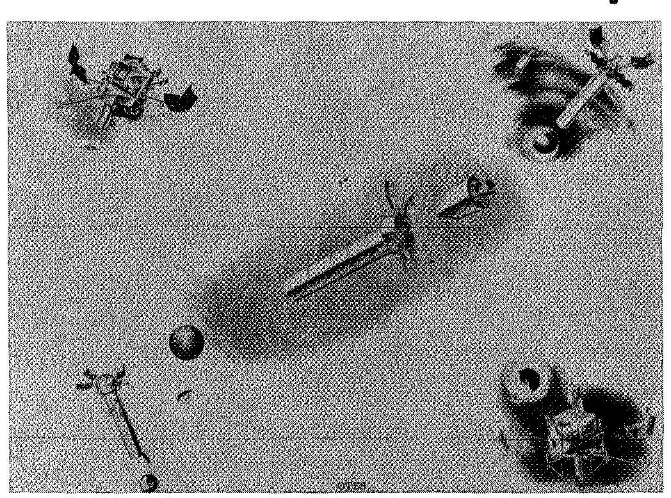
BASIC DATA GENERATED AND SIGNIFICANT RESULTS

1. There are worthwhile space flight experiments in optical technology:



OTES Experiments

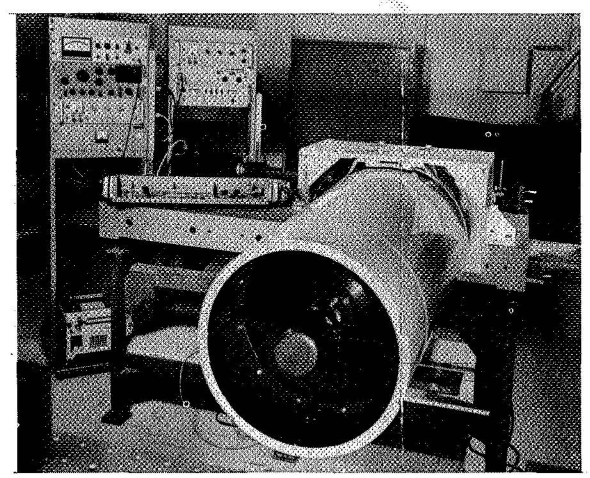
2. Four concepts were studied and the 3-meter concept is recommended. The 3-meter telescope MOTEL OTES can be launched into synchronous orbit and provide 45 days of manned operation with a single Saturn V launch.



OTES Concepts

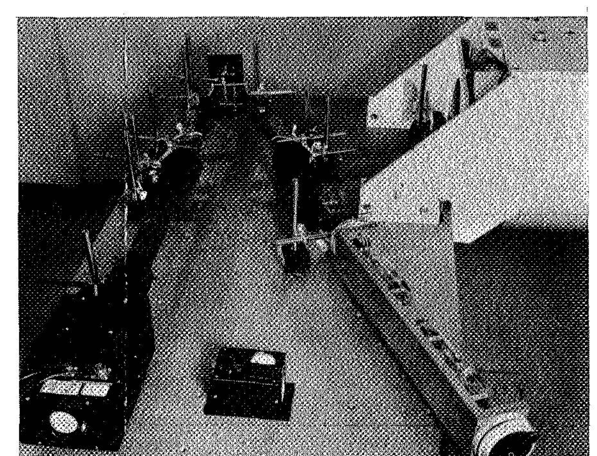
3. 1/10 arc-second laser beam tracking in the presence of man disturbances was demonstrated in the laboratory. (NAS8-20115)

Balloon launching stations



Experimental Hardware

4. 115db beam isolation between laser transmitter and receiver was obtained in the laboratory. (NAS8-20115)



Experimental Hardware

5. Laser beam wander (intensity fluctuations) was measured in the laboratory to be less than 1% in far field. (NAS8-20115)

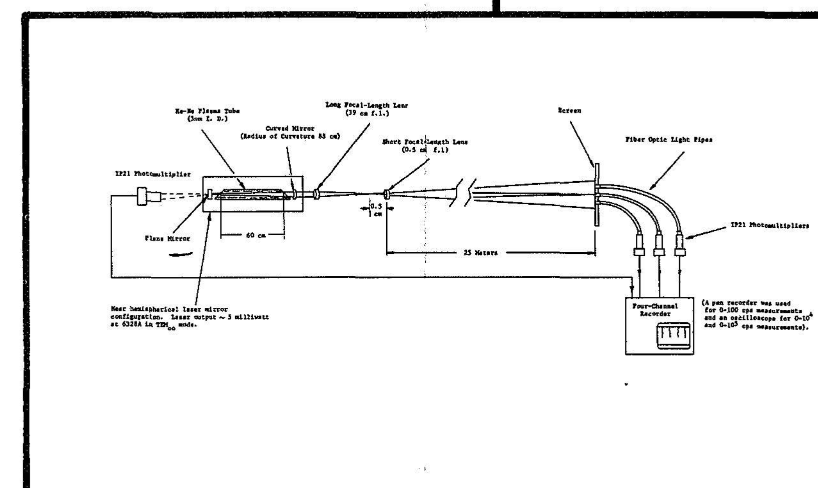
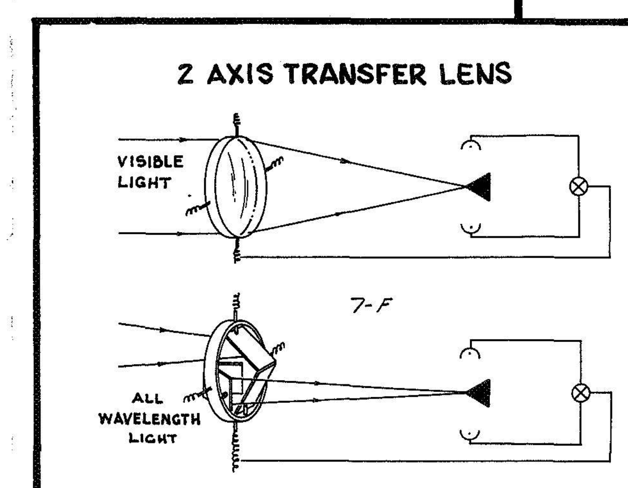


Diagram of Experimental Setup for Measurement of Intensity Stability in the Far Field of a Laser Beam

6. All-reflective transfer lens was invented for use in 2- or 3-meter space telescopes and for visible and infrared laser communication experiments.



2 Axis Transfer Lens

BASIC DATA GENERATED AND SIGNIFICANT RESULTS (Cont.)

7. The radiated power requirement computed for a 10^6 bit/second laser link at 100 million miles is 100 milliwatts.

8. Coherent and incoherent laser link calculations are completed for deep-space communication using various laser wavelengths.

9. Optimized diameter (for weight) of a 6328Å mirror used in a deep-space laser communication link is 0.838 meters; at 10.6 microns the diameter is 1.45 meters.

10. Measurement of the penetration of laser light through a laboratory-generated aerosol indicated that one fog that removed 98% of the 6328Å light only attenuated 10.6 micron light by 3%

11. The theoretical transmittance of 10.6 micron light through two atmospheres was derived as 36%.

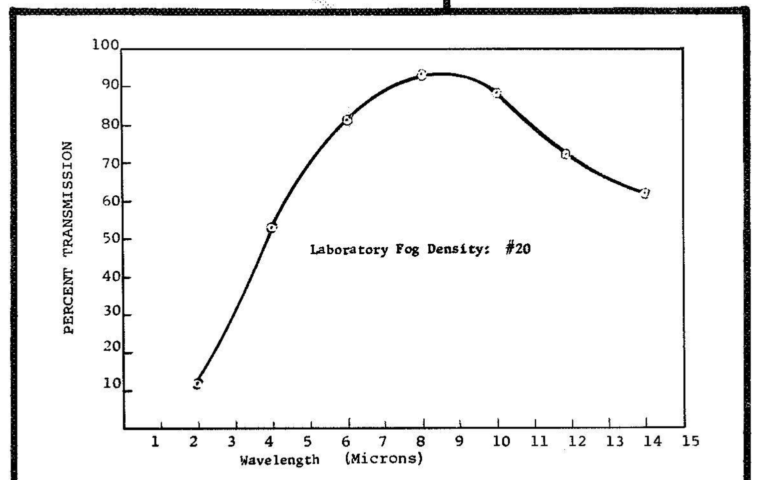
12. The cloud-free cover across the sun at one point in the United States is 89%.

13. Upgoing laser beam broadening (at 4880Å) due to the atmosphere was computed to be less than 1/2 arc-second. Downlooking scintillation and power spectrum derived theoretically.

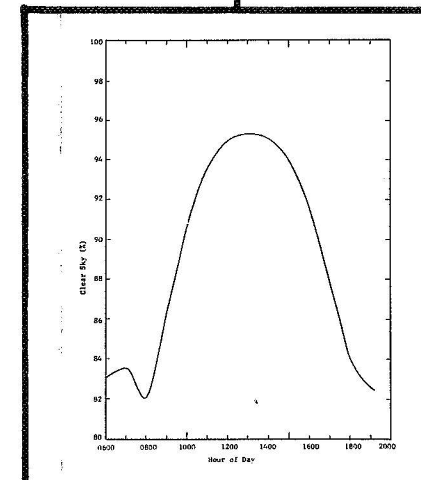
Balloon launch stations

DOWNWARD TRANSMISSION λ	INTENSITY DETECTION .6328μ	INTENSITY DETECTION 1.0μ	COHERENT DETECTION 10.6μ
RANGE - STAT. MILES	10^8 →		
TRANSMITTER APERTURE (METERS)	1	1.2	1.5
BEAM DIVERGENCE (μ RADIANS)	.63	.83	7.07
EFFECTIVE RECEIVER APERTURE (METERS)	10	10	4
RECEIVER FIELD of VIEW (SEC)	20	20	
ATMOSPHERIC TRANSMISSION (θ=60°)	.70	.9	.30
OPTICAL SYSTEM TRANSMISSION	.50	.50	.50
PRE DETECTION FILTER	.15 → .5Å .80 → 5Å	.60 → 50Å .65 → 100Å	.60 → .08μ .80 → .15μ .90 → .3μ
"BLUE" SKY $\frac{watts}{m^2\text{-}ster\text{-}\mu}$	50	5	3.4
DETECTOR	RCA 7265	RCA 7102	Ge:Hg
AT TEMPERATURE	-70°C	-70°C	30°K
DARK CURRENT (WATTS)	2×10^{-15}	10^{-14}	
D^* $\frac{cm(cps)^{1/2}}{watt}$			10^9
QUANTUM EFFICIENCY	.05	.001	.20
DOPPLER (MAXIMUM)	.35Å	.57Å	1.7 kMcps
DOPPLER RATE (MAXIMUM)	5×10^{-7}Å/sec	10^{-6}Å/sec	3.5 kcps/sec
SIGNAL PHOTOELECTRONS RECEIVED FOR EACH WATT TRANSMITTED	13×10^8	8.8×10^6	8.1×10^6
OPTICAL FILTER	.5Å	50Å	.3μ
BACKGROUND & PMT NOISE PHOTOELECTRONS/SEC.	1.35×10^{17}	3.7×10^7	

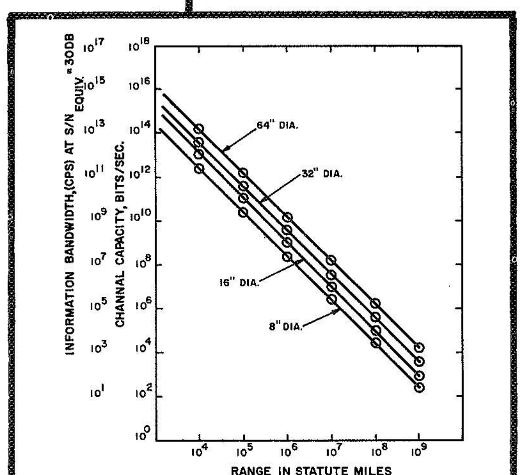
Helium-Neon, YAG, and CO_2 Communication System Comparisons



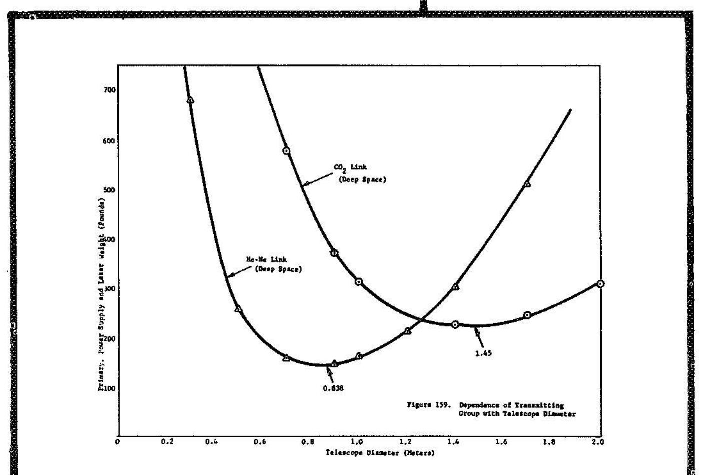
Laser Light Transmission Measured Through Fog



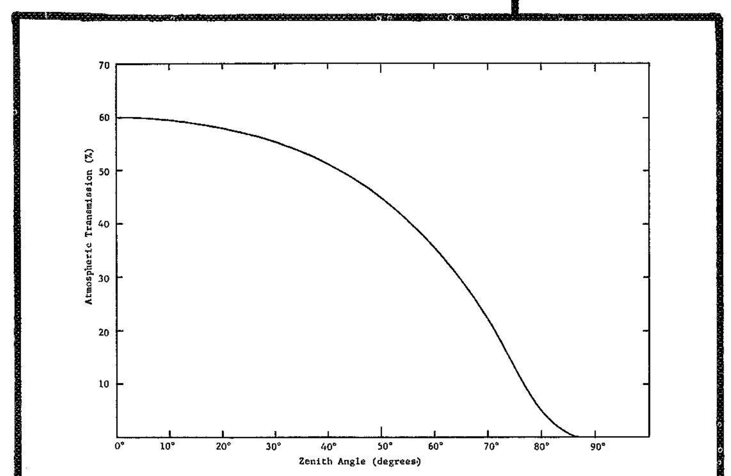
Unclouded Skies



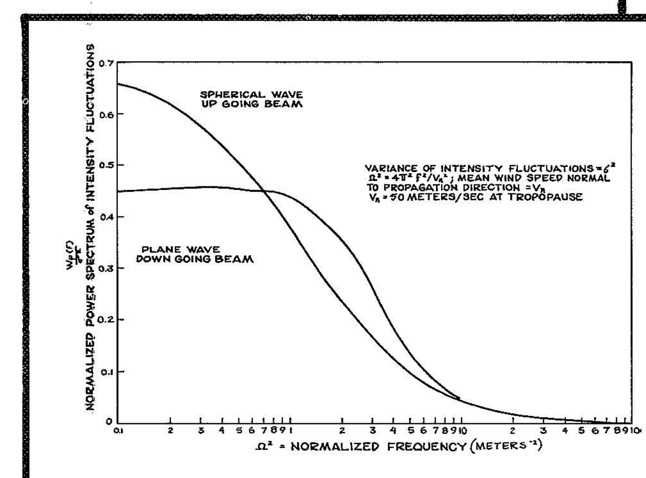
Deep Space Laser Communication Performance



Dependence of Transmitting Group Weight With Telescope Diameter



10.6 Micron Transmission



Scintillation

BASIC DATA GENERATED AND SIGNIFICANT RESULTS (Cont.)

14. Active segmented optics works. (NAS1-5198).

15. The diffraction pattern resulting from a segmented primary mirror does not degrade the performance of the optical system.

16. A super-cold telescope (-80°C) can be obtained passively. This low temperature permits a ±4.5°C gradient tolerance in a 3-meter mirror of fused quartz

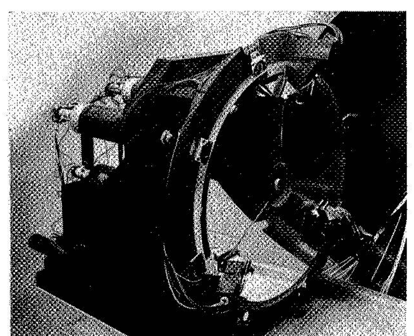
The OTES f... would present a t... nt to the 3-meter ... ss than 1°C (at -80

Balloon Launching Stations

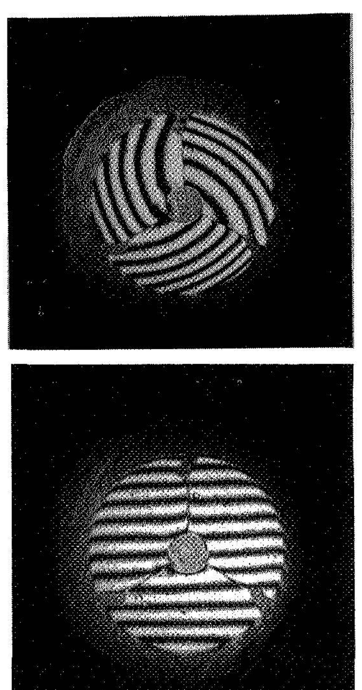
17. Theoretical calculations were prepared on the magnitude of the guide star needed for the 3-meter astronomical telescope to obtain 1/100 arc-second pointing.

18. Theoretical detrimental effects of sunlight scatter from gas molecules, aerosols and particles were computed.

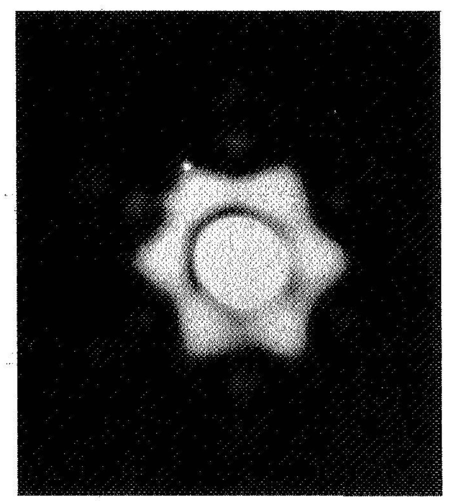
19. Thermal deformation of mirrors due to gradients derived.



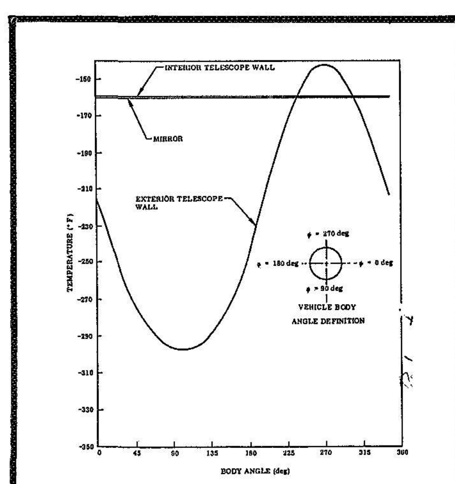
Mirror Assembly



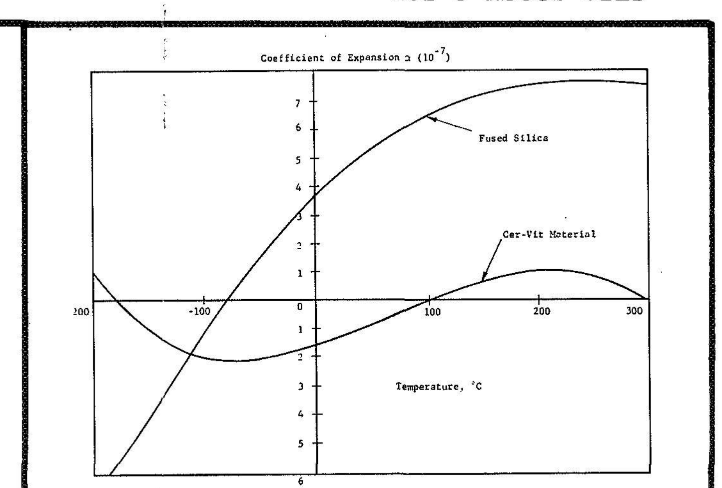
Fringe Patterns



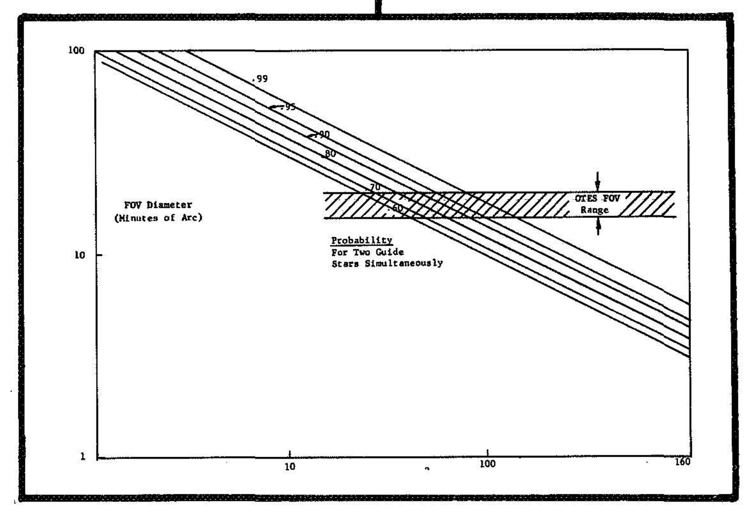
Simulated 3-Meter Segmented Primary Diffraction Pattern



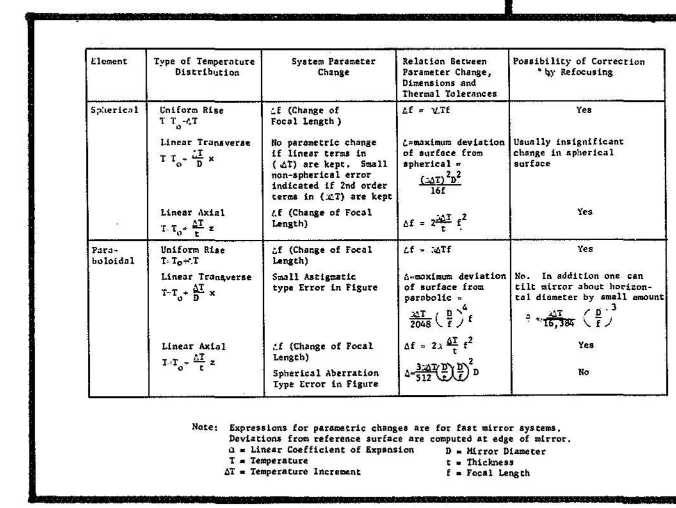
Orbit Average Temperature Profile



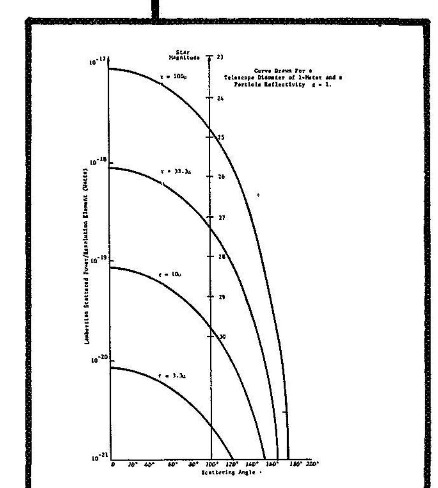
Thermal Expansion of Mirror Materials



90% Probability of at Least Two Guide Stars for 3-Meter OTES



Thermal Tolerance Data of Telescope Mirrors



Sunlight Scattered From Debris Particles as Function of Particle Size (Y) and Scattering Angle (α)

IMPLICATIONS FOR RESEARCH

There are certain optical technology research and development activities which should be conducted on the ground in the laboratory and which do not require a space test bed yet. Nevertheless, this class of R & D activities are necessary to the ultimate attainment of NASA goals in space. Projects in this category include:

- Laser and optical component space qualification.
- Further active optics laboratory development.
- 10.6 micron component research and development.
- Atmospheric measurements made on the ground, from an aircraft, and from a balloon-borne source.
- Ground station development.

There are certain OTES Experiments which are included in the present Phase I Study which can best be conducted in space, but these experiments should be conducted prior to an OTES flight. This group of space experiments in optical technology can be conducted on vehicles smaller than the contemplated Saturn V AAP Systems or these experiments can be launched "piggy-back" on earlier Saturn V flights. Experiments in this group include:

- Laser communication measurements (Experiment No. 23)
- Radiation effects (Experiments No. 11 and 15)
- Suspension systems comparison (Experiment No. 26)
- Atmospheric measurement techniques from non-synchronous orbits.

SUGGESTED ADDITIONAL EFFORT

The OTES Program should proceed with Phase II of the plan laid out by MSFC in the Statement of Work of the Optical Technology Apollo Extension System and with selected projects from the listing in IMPLICATIONS FOR RESEARCH.

LMSC-A820888 • 1 SEPTEMBER 1966

LMSC-A820888

OPTICAL TECHNOLOGY EXPERIMENT SYSTEM (OTES)

PHASE I CONDENSED SUMMARY REPORT

LMSC Input

Submitted to
The Perkin-Elmer Corporation

In Support of Prime Contract NASA 8-20255
With NASA/Marshall Space Flight Center (MSFC)
Huntsville, Alabama

Covering Effort Performed Under Subcontract No. 15653-I and IA

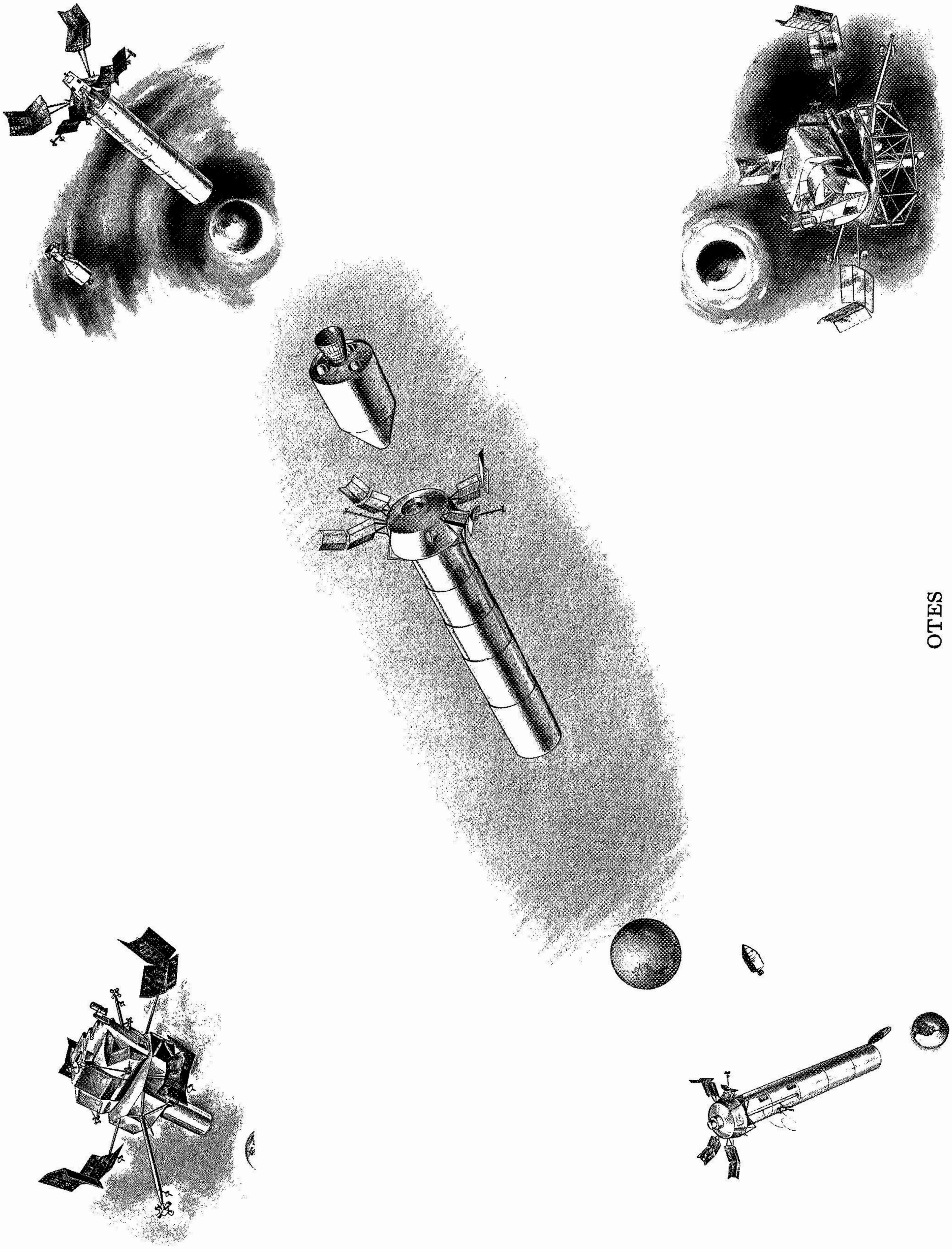
Approved W. P. Mimnaugh
W. P. Mimnaugh
OTES Program Manager

Lockheed

MISSILES & SPACE COMPANY

A GROUP DIVISION OF LOCKHEED AIRCRAFT CORPORATION

SUNNYVALE, CALIFORNIA



OTES

FOREWORD

This Condensed Summary Report briefly describes the effort accomplished by Lockheed Missiles & Space Company in support of the Perkin-Elmer Corporation activities on the Optical Technology Apollo Extension System (OTAES) study program. Results of both the Phase I and Phase IA studies are included. Material covering the optical payload and experiment studies is being prepared by the Perkin-Elmer Corporation for integration with the enclosed report and submittal to NASA/MSFC under prime contract No. NASA 8-20255. A more detailed description of the LMSC efforts is contained in the Phase I Final Technical Report (LMSC-A820889, dated 1 September 1966).

INTRODUCTION

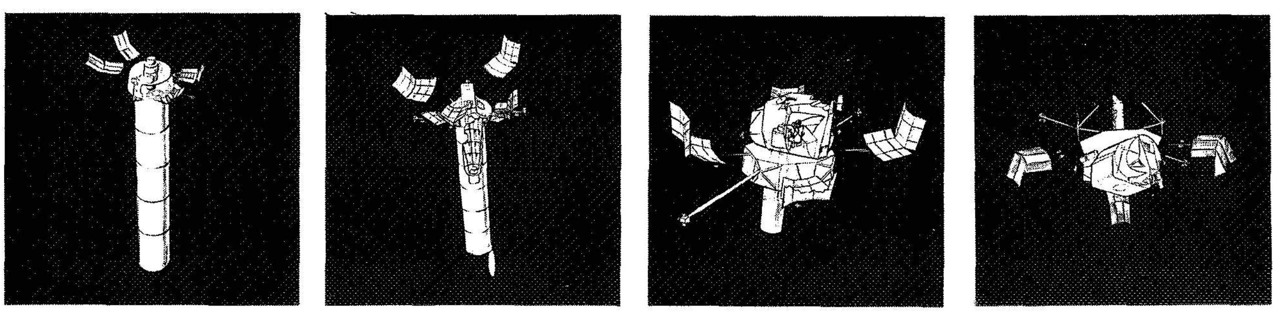
STUDY OBJECTIVES

The Perkin-Elmer Corporation (P-E) and Lockheed Missiles & Space Company (LMSC) are performing a conceptual design study on an Optical Technology Experiment System (OTES) for NASA/MSFC. As prime contractor, P-E is reviewing and selecting candidate experiments, determining requirements for performance of these experiments, and deriving potential optical/laser equipment configurations and operational sequences that will provide significant advances in optical technology. LMSC's responsibility as principal subcontractor involves the OTES spacecraft, support subsystems, and allied program activities to integrate the optical technology experiments into the Apollo Applications Program (AAP). The initial phase of the two-phase conceptual design study for the OTES Program has been completed. The results of LMSC's work are summarized in this report. The objectives of the Phase I spacecraft effort were to:

- Support experiment selection and determination of requirements
- Verify gross feasibility of experiment implementation
- Generate preliminary spacecraft conceptual configurations
- Evaluate selected OTES design approaches

These objectives were accomplished and the desired results achieved. Support data and guideline constraints were provided to assist the experiment study. The feasibility of implementing four varied experiment configurations was ascertained, resulting in the generation of four preliminary OTES concepts. One concept, involving a 3-m primary aperture, was improved in the latter portion of the Phase I study to provide significant OTES advantages. This concept demonstrates the reasonableness, with respect to spacecraft considerations, of continued OTES development.

THREE-METER TWO-METER ONE-METER HALF-METER



Preliminary OTES Concepts

RELATIONSHIP TO OTHER NASA EFFORTS

The OTES is to be an experiment in NASA's AAP. LMSC organized and conducted the OTES study within its NASA Programs organization. Under other contracts, LMSC is conducting the AAP Integration Study, the AAP Lunar Orbital Survey Missions Study, and a program-definition study of the Apollo Experiments Pallet. A related thermal study for NASA/MSFC, "Thermal Similitude in Space Environment," is underway. LMSC has participated, as prime contractor and subcontractor, in lunar-surface systems studies, is conducting the Mission Modes and System Analysis (MIMOSA) Study, and has completed the BIOLABS studies – activities involved in the 0100- and 0200-series medical and behavioral experiments currently contemplated for the AAP orbital missions. Data from these related efforts and program-peculiar generated study results confirmed the feasibility of the OTES concepts.

APPROACH AND ASSUMPTIONS

Study program direction was provided by NASA Headquarters, NASA/MSFC, and P-E personnel at program orientation meetings held between 15 Nov and 15 Dec 1965. Based upon this guidance, LMSC established tasks that defined the areas of technical interest in deriving a preliminary conceptual design. Following approval of the program planning document, preliminary studies of the program and mission constraints were conducted. These analyses resulted in a recommendation that the following parameters be used as a basis for further study:

- Orbit. 24-hr synchronous, circular, inclined 28.3 deg, equatorial crossing at the stable, stationary point nearest the optical station site (~109° W longitude)
- Payload. 21,700 lb (9,800 kg) plus Command and Service Module (CSM) and LEM adapter; optical technology to be the primary mission experiment
- Life. 2 yr (0.90 probability of success, 0.999 probability of crew survival)
- Ground Stations. Launch, ETR, Pad 39; microwave, Goldstone, DSIF; optical, new OTES station (e.g., Big Bear Lake, Calif.); manned, Houston, MSC
- Principal Control Requirements. Thermal gradient, ±0.5° F; attitude control, ± 7.5 sec of arc

Four experiment configurations were selected originally by P-E for LMSC determination of implementation feasibility and consideration of possible OTES spacecraft concepts. These experiment configurations, differing principally in the overall diameter of the primary optics, are as follows:

- Three-Meter. A seven-segment, active optic array, each segment to provide a hexagonal interface and have a diagonal dimension of 1.15 m
- Two-Meter. Three segments to be used in an active optics configuration, with provision for extended (45-day) crew participation
- One-Meter. A single-lens optic system to be incorporated into an integral LEM/OTES configuration
- Half-Meter. A single-lens primary to serve as the principal telescope element in a "test-bed" approach

Based upon these mission constraints and experiment definitions, preliminary guidelines were established for four OTES concepts. These guidelines served to constrain subsequent experiment analyses as well as spacecraft configuration studies. Four OTES preliminary concepts resulted from the Phase I efforts using these guidelines. (The preliminary spacecraft concept designations correspond to the experiment primary apertures.)

Cursory comparative evaluation of the four concepts developed during initial Phase I effort did not indicate any predominant approach based upon spacecraft considerations. Further, additional consideration of the three smaller-aperture approaches did not appear to offer any inherent modification of that conclusion. The principal disadvantages of the 3-m approach, however, was the limitation on participation by man. Thus, it was realized that if a feasible 3-m concept with extended astronaut effort could be evolved, a significant improvement in Phase I results might be realized. This consideration became a basis for extended Phase I (i.e., Phase IA) spacecraft studies. Another assumption that guided the Phase IA study was that the OTES would be placed in a synchronous, inclined orbit with a single Saturn V launch vehicle. Based upon these supplemental assumptions, a modified 3-m approach providing extended crew-participation capabilities (i.e., in excess of 45 days) was generated. The resulting OTES concept involves utilization of the Manned Optical Technology Experiment Laboratory (MOTEL) system in conjunction with the telescope.

CONCEPT DESCRIPTIONS

BASIC DATA AND SIGNIFICANT RESULTS

The four preliminary concepts and the MOTEL approach have common elements – including the booster and mission constraints, the basic operational sequence, and spacecraft support subsystem configurations. In addition, many of the crew operations are common to the four approaches (particularly the three smaller-aperture systems). A Saturn-class vehicle and its support facilities have been designated for the OTES. These systems were considered in preliminary support studies and form a part of the overall OTES concept.

A 15-event, typical operational sequence describes the anticipated OTES concepts:

1. Liftoff from ETR on the Saturn V vehicle
2. Start of S-II thrusting
3. Jettison of the Launch Escape System (LES) and Interstage
4. Start of S-IVB thrusting
5. Insertion into an Earth parking orbit
6. Initiation of a transfer orbit
7. Coast to synchrononous (19,323-nm, 35,810-km) altitude
8. Circularization of orbit and removal of injection errors
9. Start of transposition and docking
10. Separation of S-IVB
11. Initiation of OTES erection (CSM docked) and initial operation (OTES Phase A)
12. OTES manned operation phase, 45 days (OTES Phases B and C)
13. Autonomous operation – Earth-oriented, 5 – 12 mo (OTES Phase D)
14. Autonomous operation – space-oriented, 6 – 18 mo (OTES Phase E)
15. Maintenance (resupply) operation – manned mission (OTES Phase F)

The first 10 events are related to a representative Saturn V launch in the AAP. The last 5 are program events involving 6 phases peculiar to the OTES.

Primary (baseline) configurations have been selected tentatively for each of the OTES spacecraft subsystems following preliminary investigation of each of the areas; in addition, secondary approaches have been considered. In several subsystems the secondary equipment has been included as a back-up or redundancy feature of the OTES conceptual designs.

OTES SUBSYSTEMS

Subsystem	Primary	Secondary
Structure	3-m: telescoping array/MOTEL 2-m: independent OTES 1-m: integrated LEM/OTES Half-meter: cylindrical test bed	3-m: telescoping array 2-m: integrated LEM/OTES 1-m: independent OTES Half-meter: CSM/Pallet configuration
Thermal	Semipassive materials	Physical isolation and arrangement; vehicle time constant
Power Supply	Unfurled solar arrays	Body-mounted cells
Orbit Propulsion	Attitude control-active system application	Independent monopropellant system
Attitude Sensing	Microwave interferometer	Star field mapper
Attitude Control	Momentum storage (precession wheels)	Magnetic torque bars; active system (cold gas)
Microwave Communications	Apollo unified S-band telecommunications system	Apollo unified S-band telecommunications system

Crew participation was analyzed for general applicability and for the specific OTES mission. Manned support of the OTES was considered for eight primary experiments:

- Telescope erection and alignment
- Mirror segment replacement
- Crew perturbation effects
- Atmospheric scintillation and image jitter
- Utilization of mirror coating facility
- Measurement of off-axis performance
- Evaluation of space radiation effects
- Use of scatterplate techniques for mirror figure measurement

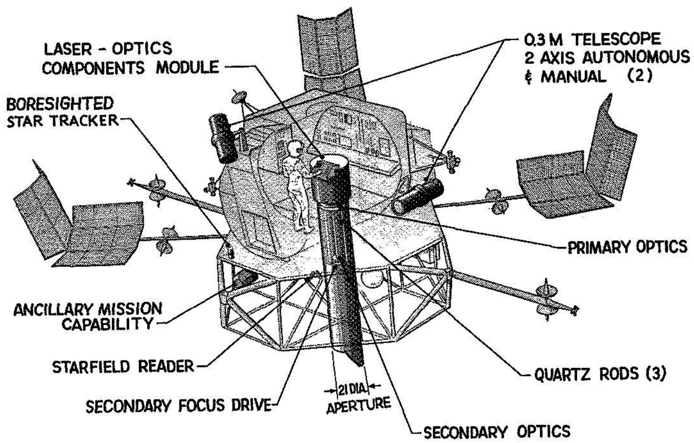
Utilization of the available launch volume within the LEM adapter was a significant constraint to the development of OTES configurations. Each approach can be accommodated, however, while providing a limited volume for inclusion of alternate (non-optical) payload experiments. The smaller-aperture concepts are particularly amenable to inclusion of auxiliary experiments, both on and within the LEM structure. Each of the aspects peculiar to a specific OTES concept is considered in the following paragraphs.

HALF-METER CONCEPT. The half-meter concept, while not demonstrating extensive growth in large apertures for space astronomy, does have several significant advantages. This "test-bed" approach relies upon simplified equipment and techniques, in both the optics and spacecraft. Maximum utilization is made of Apollo-proven equipment — the LEM ascent stage, descent stage, and support structure as configured for an Apollo mission. (The ascent- and descent-stage engines are removed and the LEM ascent stage is uprated to provide the 45-day LEM Lab capability.) Optical technology experiments are housed within the available volume, primarily within the descent-stage structure. Simultaneous Earth-oriented and space-oriented operation with parallel telescope provides a significant feature of the half-meter approach. Considerable flexibility exists in equipment arrangement. The main half-meter mirror is located in the space normally occupied by the LEM descent-stage engine, and is space-oriented. A two-axis gimbal permits continual tracking of selected space areas, while a simultaneous optic link is maintained between the auxiliary spacecraft telescopes and the ground station.

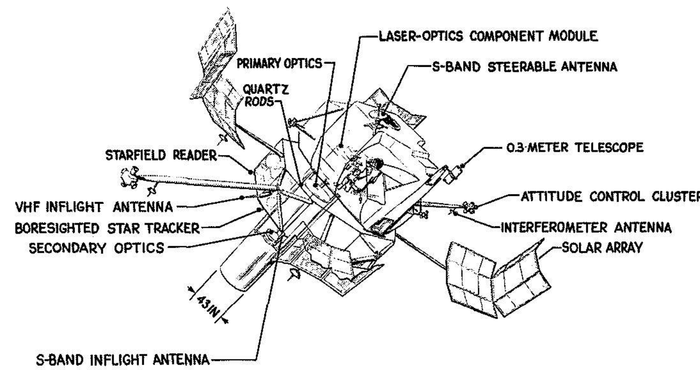
Crew participation is obtained by use of the CSM and LEM Lab provisions. Following the 45-day manned phase of operation, the CSM disengages from the OTES/LEM and de-orbits. The LEM support systems are modified (supplemented) from the configurations employed for an Apollo mission. (An alternate possibility is the uprating, or life-extension, of the existing equipment.) Following a purging and transition mode from the manned to the autonomous operational configuration, the subsystem elements are utilized as the principal system support and control equipment for the remainder of the 2-yr mission.

ONE-METER CONCEPT. The 1-m approach involves an integrated OTES/LEM Lab configuration permitting extensive crew participation and/or evaluation. The limited primary optic aperture (in comparison with the 3-m or 2-m concept) facilitates design of an integrated structure. As with the half-meter approach, the descent-stage and ascent-stage engines are eliminated, and a modified LEM support structure is used. The primary mirror is within the LEM Lab housing, allowing immediate and ready crew access. Nonperturbated manned operations (i.e., physical isolation of the astronaut) are possible by remote control from the CSM or by EVA operation. Telescope support is provided by the LEM Lab mounted equipment which controls the integrated configuration. Standardized LEM Lab subsystem equipment has been supplemented to meet the fine thermal and attitude control requirements of the OTES. Supplementary solar arrays are employed for the increased power requirements of the OTES. Orbital propulsion and microwave communication equipment, as presently configured for the LEM, should provide systems adequate for the integrated 1-m concept. The 1-m approach allows extensive evaluation of man in the synchronous, inclined orbit. A portion of the available weight allocated to alternate payloads can be utilized for biomedical evaluations.

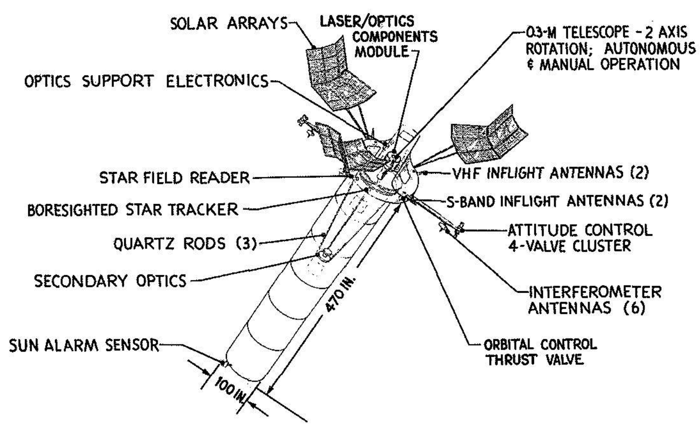
HALF-METER



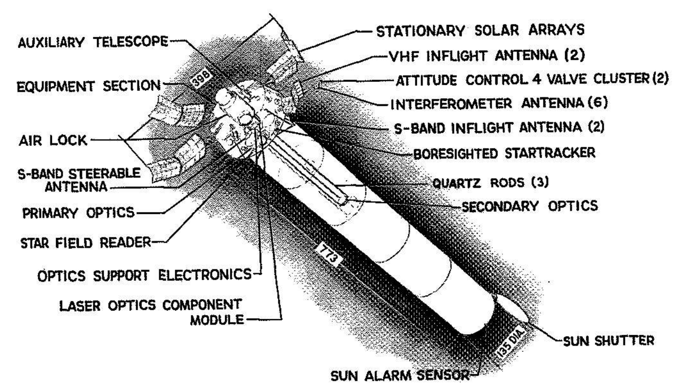
ONE-METER



TWO-METER



THREE-METER (LIMITED)



Four Preliminary OTES Configurations

Following the 45-day manned phase, the CSM is separated for the astronauts' return to Earth. The integrated LEM/OTES configuration is placed in a transition mode in which active environmental control is deactivated, all gases are purged, and the environmental control system (ECS) is in the autonomous mode of operation. Evaluation (and possible subsequent modification) of the existing LEM Lab configuration should permit achieving the desired 2-yr operating life capability.

TWO-METER CONCEPT. The 2-m concept provides a 45-day manned operational phase and extended crew participation made possible by use of the LEM ascent stage as a life cell. (The LEM descent- and ascent-stage engines are eliminated from the Apollo-LEM configuration.) Two main approaches were considered in deriving the 2-m configuration. One involves an integrated telescope/LEM (LEM Lab) design, as selected for the OTES 1-m and half-meter concepts, to permit extensive use of the LEM structure for subsystem support and equipment mounting. In addition, permanent direct access from the LEM laboratory to the telescope and simplified subsystem requirements were envisioned (e.g., single microwave communication and orbital propulsion systems might be used for both the manned and unmanned phases of operation). These advantages are particularly apparent in the stowed mode. The limited volume within the LEM adapter required redesign of the LEM support structure necessary for the 30,000-lb Block II LEM. This revised descent-stage structure design provides a significantly increased, but still limited, volume for addition of an OTES experiment. A horizontal (i.e., in the launch position) telescope array permanently attached to the uprated LEM ascent stage (i.e., LEM Lab) was considered. This approach, however, has three distinct disadvantages:

- The unsymmetrical LEM ascent stage/OTES arrangement results in difficult thermal and attitude control problems for all phases of operation.
- Crew support of an OTES experiment while providing physical isolation (i.e., zero perturbations on the telescope due to man's presence) must be accomplished by EVA.
- Extensive modification of the LEM ascent stage would be required to provide a 2-yr operating life capability; e.g., outgassing of the LEM Lab following crew participation could present a problem. All LEM subsystem elements, with the possible exception of the microwave communications and orbital propulsion systems, would have to be redesigned, replaced, or supplemented to support the OTES for the 2-yr operational period.

Therefore, an approach involving a separable LEM/OTES was derived. The LEM support structure is modified and the telescoped array is stowed in a vertical (launch position) arrangement. This system includes an equipment housing which incorporates all required support elements for an autonomous phase of operation. In the stowed position, ready access is available from the LEM to the OTES. Five telescoping actions are required for erection (including sun-shade provisions). The LEM Lab remains attached to the OTES during erection and initial stabilization, and for preliminary experiments requiring direct crew participation. Following this aspect of the mission, the LEM Lab (and CSM) are separated from the OTES. Continued monitoring, remote control, and EVA support of the optical technology experiments are provided from the CSM/LEM Lab, which orbits close to the OTES during the 45-day manned phase. (Alternate experiments and biomedical evaluations also are accomplished by the CSM/LEM Lab during this period.)

THREE-METER CONCEPT. The principal features of the preliminary 3-m concept are an extremely large primary mirror and the elimination of any life-cell capability beyond that provided by the CSM in the normal Apollo launch configuration (i.e., 14-day manned operation). The preliminary 3-m OTES uses the same basic configuration for the crew operation, Earth-oriented, and space-oriented phases. From the stowed position, telescoping action provides the basic telescope and sun shade of the 118-in. (3-m) optics. Three pairs of quartz locating rods are extended, rotated, and locked into position to fix the secondary mirror. An auxiliary telescope is rotated into position from a gimbaled mechanism on the side of the main telescope. The four solar arrays are unfurled and locked into position and the sun shutter is deployed. All manned effort is EVA with simultaneous monitoring from the CSM.

The subsystem and support equipment are located principally in the structure immediately behind the primary mirror. This volume is more than adequate for anticipated subsystem equipment. Access to the various key equipment locations facilitates crew servicing either during the initial 14-day operating phase or during a subsequent maintenance mission. For the space-oriented phase of operation, the OTES is rotated 180 deg. The gimbaled (two-axis) auxiliary telescope maintains Earth orientation; this 0.3-m system provides a laser communication link with the optical ground station. The entire system has the inherent capability of being mounted in a spent-stage experimental support module (SSESM) or AAP rack if desired.

COMPARISON OF PRELIMINARY OTES CONCEPTS

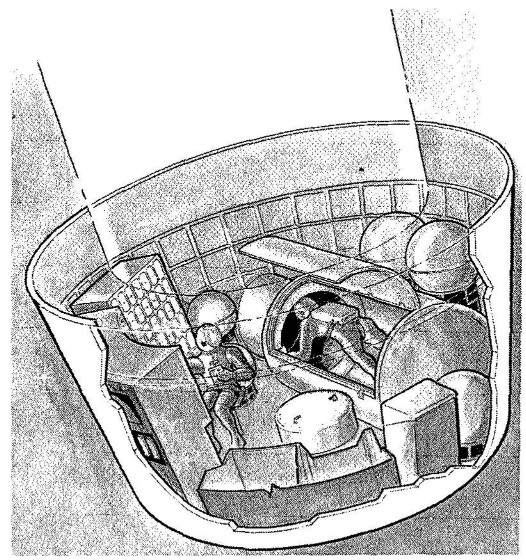
Principal Parameter	Three-Meter (Limited)	Two-Meter	One-Meter	Half-Meter
Available Weight, Exclusive of Life Cell (lb)	15,000	9,000	7,000	6,000
Alternate Experiment Allocation (lb)	6,700	3,000	5,000	3,000
Major Erection Activities	5 telescoping actions; secondary mirror; solar arrays; sun shade	5 telescoping actions; secondary mirror; solar arrays; sun shade	Solar arrays	Solar arrays
Available Manned Support (EVA); LEM/CSM Support Span	9 manhours; 14 days	250 manhours; 45 days	250 manhours; 45 days	250 manhours; 45 days
Power (kw)	1	1	1	1
Chief Disadvantage	Limited support and evaluation by man	"Tight" design in stowed position; extensive erection	Integration of OTES into LEM configuration; disturbances by man	Minimum astronomical capability; disturbances by man
Key Feature	Ready growth to 1980 space telescope; conservative spacecraft design	Extensive crew support; accommodation of experiment requirements	Additional crew activities and experiments	Maximum utilization of LEM hardware

The four preliminary OTES concepts were subjected to a cursory comparison. The principal disadvantages and key features of each approach tended to offset one another and, from a spacecraft viewpoint, there was not a dominant advantage for any one concept. Further, the principal disadvantages of the smaller-aperture concepts were inherent and not readily amenable to minimization. A significant improvement, however, could be achieved if a 3-m concept could be evolved permitting more extensive crew participation within the limitations imposed by a single Saturn V Launch. Generation of such an approach became an objective of Phase IA spacecraft effort. A brief review of the potential manned experiments led to Phase IA revision of the original Phase I 3-m concept, which included an airlock attached to a minimum unpressurized area or experiment support section. The revised concept includes a laboratory section behind the primary mirror. This section, designated as MOTEL (Manned Optical Technology Experiment Laboratory), includes a minimum-volume airlock for EVA. The MOTEL, designed for either pressurized or unpressurized operations, is supplied from the ECS of the Extended Command and Service

Module (XCSM); the ECS is supplemented to extend the period of operation from 14 days to a minimum of 45 days. The additional supplies required for the ECS and life-support expendables are stored in the MOTEL. By the combined utilization of the MOTEL, EVA, and remote operations from the XCSM, the desired extension of participation by man with a 3-m aperture optical system can be provided. The integrated OTES design is such that all of these elements can be accommodated and placed in orbit with a single Saturn V launch vehicle. Provision for subsequent maintenance and resupply missions is included.

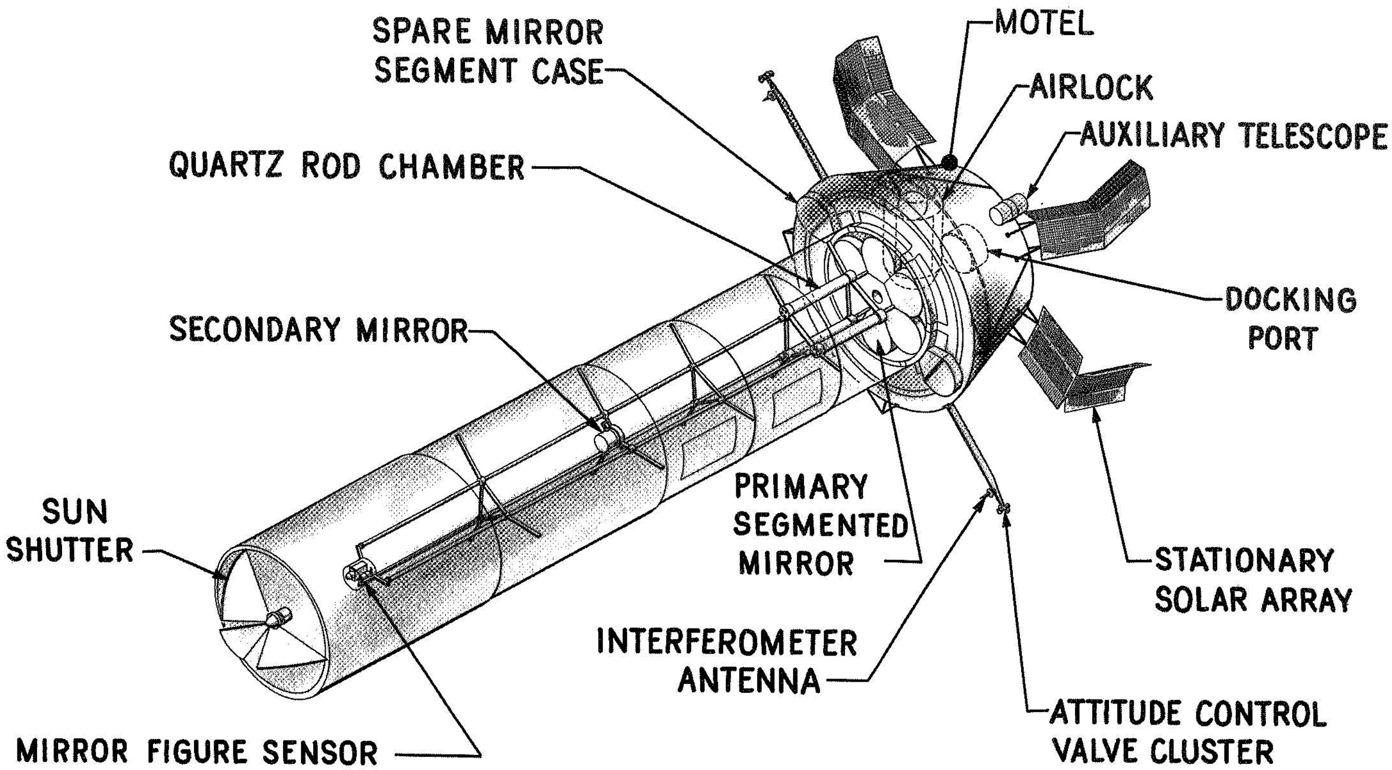
The MOTEL has certain features that allow extensive participation by an astronaut-astronomer; the functions with additional activity are:

- Experiment alignment – The astronaut has access to the back of the primary mirror and a majority of the experiment packages and can participate in basic alignment operations, thereby reducing the amount of automation required in the OTES.
- Coarse acquisition – The initial stationkeeping and orbital positioning of the OTES are performed from the XCSM prior to the extension of the telescope. Upon completion of the telescope extension and alignment operations, the astronaut in the MOTEL can initiate the coarse acquisition and monitor the fine acquisition modes. After data evaluation, the astronaut-astronomer can select additional targets and control the coarse and fine acquisition of the new targets.
- Experiments – The astronaut can be integrated into certain of the experiments where man-created disturbances will not affect the data acquisition. With man in the experiment cycle, a considerable amount of time and a minimum of automatic equipment are needed. The astronaut-astronomer can make a "quick-look" evaluation of the data and make decisions regarding the experiment.



MOTEL Concept

- Modifications – The contiguous access to the experiments permits the astronaut to make minor modifications to the equipment to repair flight damage, improve the data-recording loop, and update the components as operating techniques improve or state-of-the-art advances are made.
- Replacements – The astronaut can replace experiments, subsystem components, or experiment black boxes. The OTES preliminary design phase will stress the replacement philosophy.
- Growth – Since the OTES is for long-duration missions (2 to 10 years), the system will be designed for growth as a result of scientific advances or additional requirements resulting from data evaluation. The MOTEL approach facilitates such growth.
- Future Replenishment – The laboratory provides storage space for life-support and experiment expendables. Logistic vehicles recover scientific data and replenish the expendables periodically.



OTES Three-Meter/MOTEL Configuration

The three crewmen live in the XCSM, which periodically docks with the OTES. While it is docked, one or two crewmen can enter and work in the life cell or MOTEL. The MOTEL is supported by the life-support system contained in the Command Module (CM), and has a passive thermal-control system which maintains MOTEL temperatures between 50 and 100° F, permitting occupancy by the crew for periods of several hours without discomfort.

The volume of the MOTEL (775 cu ft, including an 80-cu-ft airlock) permits its use for expendable stores which are transferred to the CM as needed; a 3-day supply is always kept aboard the CM. Off-loading permits more room within the CM, improving habitability and providing space for the control-display and electronics equipment used for remote control of the telescope.

Egress from the CM and the MOTEL is accomplished through the small airlock in the MOTEL. This conserves atmosphere which would be expended in leaving directly from the CM. During periods requiring fine attitude control, the CM separates from the MOTEL telescope and controls the system remotely.

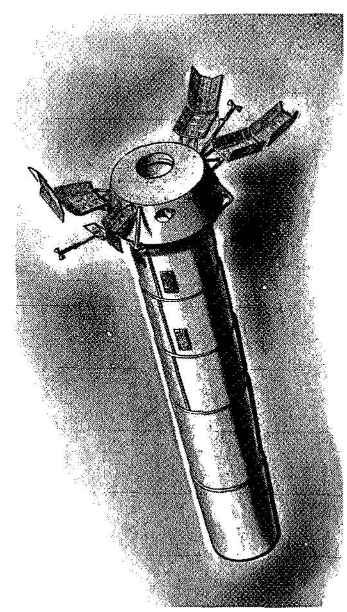
CONCLUSIONS

STUDY LIMITATIONS

Since the primary Phase I emphasis, of necessity, was upon experiment review and selection, the spacecraft study was limited to conceptual feasibility and support. The nonavailability of experiment details constituted an initial study constraint. However, based upon the available data and preliminary considerations in each of the critical areas, an approach accommodating both a 3-m optical configuration and extended participation by man appears reasonable and is recommended for Phase II study. The OTES concept has several significant advantages and can be accommodated by a single Saturn V launch. Hence the primary conclusion of the Phase I OTES spacecraft studies is that the recommended conceptual design appears feasible and warrants more detailed analysis during Phase II.

RESEARCH IMPLICATIONS AND SUGGESTED ADDITIONAL EFFORT

Additional significant conclusions of the Phase I spacecraft effort are that telescope temperature gradients of less than 1° F are possible by use of passive, superinsulation techniques, and that limited (50 to 100° F) environmental control of the MOTEL is achievable with semipassive methods. A 24-hr, synchronous, circular orbit inclined 28.3 deg is recommended for the OTES. If an equatorial crossing of approximately 109° W longitude is feasible (i.e., compatible with an optical station location at 117° W longitude), anticipated spacecraft orbit perturbations are minimized.



The OTES Concept

Implementation of any of the four OTES concepts is feasible, and no major impediment to development is apparent. Quantification of system parameters for the recommended concept is suggested as a principal Phase II task. This would include dynamic, modal, and/or system error analyses; detailed investigation of critical spacecraft mechanisms; consideration of manned operations for each of the delineated experiments; and allied program-definition activities. OTES Phase I results of the spacecraft conceptual design study effort may be summarized as follows:

- Support for experiment selection and for establishment of requirements
- Verification of feasibility of experiment implementation
- Generation of spacecraft concepts for postulated experiment configurations
- Delineation of a recommended concept

Recommendations for Phase II effort are:

- Support for experiment refinement
- More detailed consideration of the 3-m/MOTEL approach
- Generation of final conceptual design recommendations
- Establishment of basis for OTES preliminary design and development program